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We demonstrate the possibility of fabricating an infrared transmitting waveguide by burying fiber in chalcogenide glasses. Two highly mature chalcogenide glasses are used for these experiments. GASIR glass from Umicore IR Glass, Olen, Belgium, with the composition of $Ge_{22}As_{20}Se_{58}$ is used to draw fibers that are then buried in an As_2S_3 glass substrate. The glasses we used are compatible, and we obtained a high quality interface. We performed a transmission test with a CO_2 laser at $9.3\,\mu$m. The potential for extremely low loss planar waveguides is discussed. © 2008 Optical Society of America

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1. Introduction

Infrared transmitting waveguides are actively studied for many potential applications ranging from pollutant detection to exoplanets search [1–4]. The European space mission DARWIN [5] is conceived for the first direct search of terrestrial exoplanets and to achieve unprecedented spatial resolution in the infrared wavelength region. The goal is to find planets with life conditions by detecting the presence of ozone, water, and carbon dioxide in the atmosphere of these planets. These substances, which are necessary for life, have their fingerprint absorption in the 6–20 μm region. Another reason why the DARWIN mission works at this wavelength region is that there is a much lower emission intensity difference between the planet and the nearby star [5]. One of the most important components is a single-mode waveguide that functions between the 6 and 20 μm range for wavefront filtering to perform destructive interference for light from the star and to reveal the planets with much less light emission.

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Chalcogenide glasses are transparent in the near- and mid-infrared regions of the spectrum (0.5–10 μm for sulfides, 0.8–12 μm for selenides, and up to 20 μm for tellurides [6,7]). The glasses have already been applied as different optical material, such as prisms, plates, filters, lenses, and coatings. We are particularly interested in telluride glasses, because of their large spectral range. The commonly used techniques for fabrication of waveguides are fiber drawing and thin-film deposition [8–10]. The main advantages of fibers are associated with the highly circular waveguide with low optical losses.

2. Waveguide Fabrication

We propose to use an innovative technique to fabricate an integrated optics device by fiber burying in glass substrates. To demonstrate the feasibility, we selected two highly mature glasses: the GASIR glass commercialized by Umicore IR Glass, Olen, Belgium, with the composition of $Ge_{22}As_{20}Se_{58}$ and the well-known As_2S_3 glass. The experimental procedure for fabrication of chalcogenide glasses and fibers has been described elsewhere [11] and consists of putting high purity raw materials into a silica tube that is sealed under vacuum. The tube that contains

Table 1. Physical Properties of $Ge_{22}As_{20}Se_{58}$ and As_2S_3 Glasses

Composition	Glass Transition Temperature (°C)	Refractive Index at 10 μm	Thermal Expansion
$Ge_{22}As_{20}Se_{58}$	292	2.49	$17 \times 10^{-6}\,K^{-1}$
As_2S_3	170	2.38	$20 \times 10^{-6}\,K^{-1}$

the mixture is homogenized in a rocking furnace, and a glass rod is then obtained by cooling the tube in air. Glass substrates are obtained by slicing the rod into disks and then polishing the slices. Fibers are produced by drawing the rod.

Table 1 shows the glass transition temperature Tg and refractive index n for the two selected glasses. It is important to have a Tg of the fiber significantly higher than that of the substrate to prevent deformation of the fiber during a burying process by heating the substrate to a softening temperature. The two glasses have compatible refractive indices to form the core and the cladding of the waveguide. It is important to point out that the refractive index can be modified on a large scale by making a slight change in the glass composition. The As_2S_3 substrate has a higher thermal expansion coefficient than the $Ge_{22}As_{20}Se_{58}$ glass fiber, which means there is a compression on the fiber that makes it favorable to increase the strength of the component.

The fiber burying process is schematically represented in Fig. 1: a GASIR fiber is placed on a polished As_2S_3 glass substrate. Then, another polished As_2S_3 glass substrate is laid upon it. Then all is heated to a temperature higher than the glass temperature of the substrates but lower than the glass temperature of the fiber. This operation allows for the softening of the bulk while the fiber maintains its shape. A pressure of approximately 10 g/cm is applied to the top substrate, and the fiber is then progressively buried in the two substrates. The optimized burying temperature is appoximately 220 °C. After 1h at this temperature, the substrates that contain the fiber are annealed at 170 °C for 1 h before being cooled to room temperature at a rate of approximately 20 °C/h. One example of the obtained samples is shown in Fig. 2 with two buried fibers.

3. Experimental Results

The interface between the fiber and the substrate has been observed with an optical microscope after

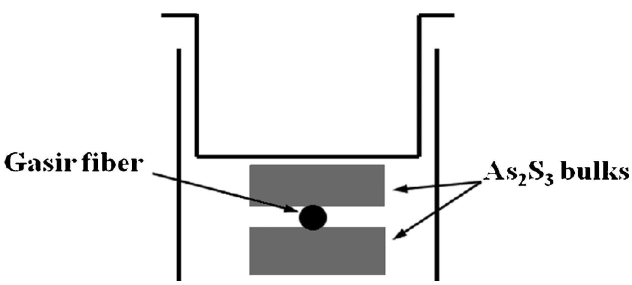

Fig. 1. Schematic representation of the setup used for chalcogenide fiber burying.

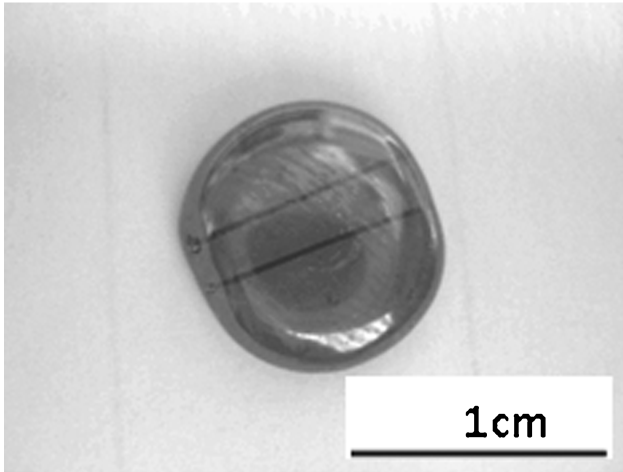

Fig. 2. Sample of $Ge_{22}As_{20}Se_{58}$ fiber buried in an As_2S_3 substrate.

polishing (Fig. 3). It is clear that no bubble or other imperfection can be observed. The fiber diameter is approximately 40 μm. The transmission property of this waveguide was then tested with a CO_2 laser emitting at 9.3 μm. The laser beam was injected into the waveguide through a $Te_2As_3Se_5$ multimode fiber fabricated in our laboratory. The output signal profile is analyzed with an infrared camera that operates between 8 and 12 μm (Fig. 4). The results are shown in Fig. 5. It seems that there are essentially two modes that emerge from the waveguide. Of course, the 40 μm diameter of the fiber is too large to obtain a single-mode waveguide, which we selected to facilitate the light injection and the feasibility demonstration although it is difficult to measure the optical losses of the waveguide. The results should be close to the fiber losses that were measured by use of the conventional cutback technique for two reasons. First, the fiber does not have any deformation during the fiber burying process and second, the interface between the fiber and the substrate does not present noticeable defects. The waveguide losses should be close to the fiber losses. The loss at 9.3 μm

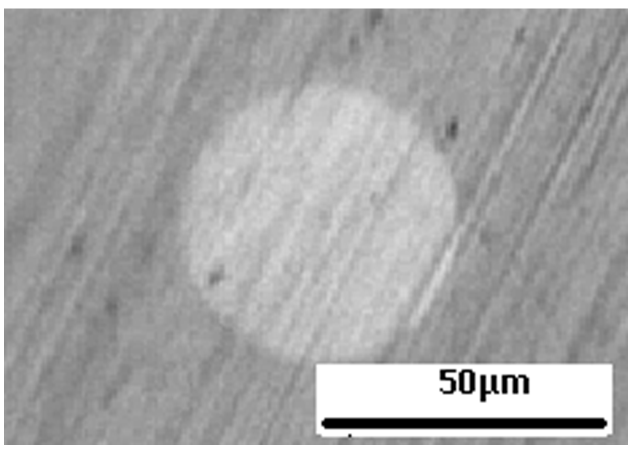

Fig. 3. Interface between the fiber and the substrate observed under an optical microscope.

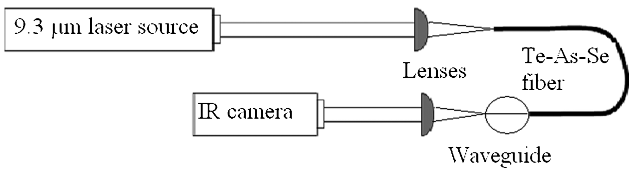

Fig. 4. Setup for transmission experiments with a CO_2 laser.

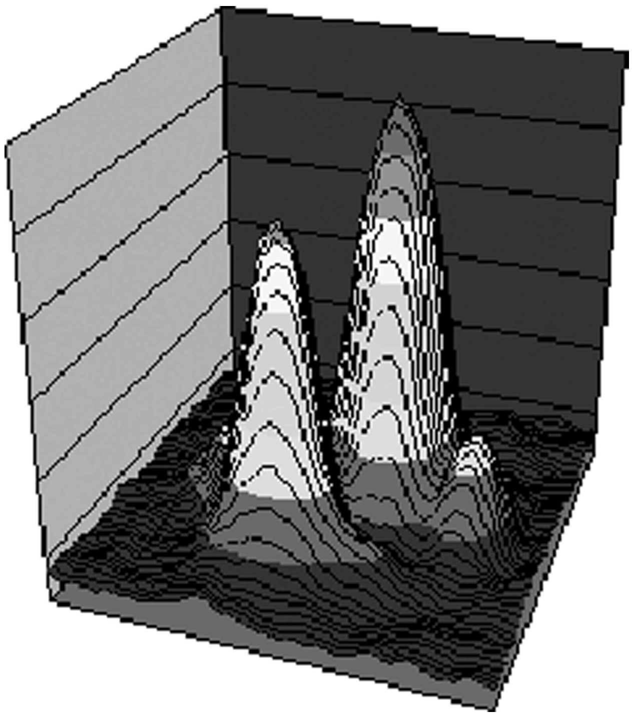

Fig. 5. (Color online) Output beam profile of the waveguide obtained by burying $Ge_{22}As_{20}Se_{58}$ fiber in a As_2S_3 substrate with a $9.3\,\mu$m laser source.

is 0.04 dB/cm. Additional research will be undertaken on the optimization of fiber diameter and on the refractive-index difference to obtain a monomode waveguide. A core fiber with an approximately $10\,\mu$m diameter and a refractive-index difference lower than 10^{-2} compared with the substrate should allow a single-mode waveguide. The optical quality of the fiber is the key parameter to achieve a low-loss waveguide.

References

1. J. Mulrooney, J. Clifford, C. Fitzpatrick, and E. Lewis, "Detection of carbon dioxide emissions from a diesel engine using a mid-infrared optical fibre based sensor," Sens. Actuators A **136**, 104–110 (2007).
2. C. Vigreux-Bercovici, E. Bonhomme, and A. Pradel, "Transmission measurement at $10.6\,\mu$m of $Te_2As_3Se_5$ rib waveguides on As_2S_3 substrate," Appl. Phys. Lett. **90**, 011110 (2007).
3. P. Lucas, M. A. Solis, D. Le Coq, C. Juncker, M. R. Riley, J. Collier, D. E. Boesewetter, C. Boussard-Plédel, and B. Bureau, "Infrared biosensors using hydrophobic chalcogenide fibers sensitized with live cells," Sens. Actuators B **119**, 355–362 (2006).
4. V. S. Shiryaev, J.-L. Adam, X. H. Zhang, C. Boussard-Plédel, J. Lucas, and M. F. Churbanov, "Infrared fibers based on Te-As-Se glass system with low optical losses," J. Non-Cryst. Solids **336**, 113–119 (2004).
5. C. V. M. Fridlund and F. Capaccioni, "Infrared space interferometry—the DARWIN mission," Adv. Space Res. **30**, 2135–2145 (2002).
6. S. Danto, P. Houizot, C. Boussard-Plédel, X.-H. Zhang, F. Smektala, and J. Lucas, "A family of far-infrared transmitting glasses in the Ga–Ge–Te system for space applications," Adv. Funct. Mater. **16**, 1847–1852 (2006).
7. A. A.Wilhelm, C. Boussard-Plédel, Q. Coulombier, J. Lucas, B. Bureau, and P. Lucas, "Development of far-infrared-transmitting Te based glasses suitable for carbon dioxide detection and space optics," Adv. Mater. **19**, 3796–3800 (2007).
8. L. Le Neindre, F. Smektala, K. Le Foulgoc, X. H. Zhang, and J. Lucas, "Tellurium halide optical fibers," J. Non-Cryst. Solids **242**, 99–103 (1998).
9. C. Vigreux-Bercovici, L. Labadie, J. E. Broquin, P. Kern, and A. Pradel, "Selenide and telluride thick films for mid and thermal infrared applications," J. Optoelectron. Adv. Mater. **7**, 2625–2634 (2005).
10. P. Houizot, C. Boussard-Plédel, A. J. Faber, L. K. Cheng, B. Bureau, P. A. Van Nijnatten, W. L. M. Gielesen, J. Pereira do Carmo, and J. Lucas, "Infrared single mode chalcogenide glass fiber for space," Opt. Express **15**, 12529–12538 (2007).
11. X. H. Zhang, Y. Guimond, and Y. Bellec, "Production of complex chalcogenide glass optics by molding for thermal imaging," J. Non-Cryst. Solids **326–327**, 519–523 (2003).